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Discussion Paper

Airborne Contaminants and Aquatic Systems: An Assessment of Research Needs

Pamela Stokes

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"Fish cannot live in water that is too pure."

Chuang Tzu

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FOREWORD

Many of the organic and inorganic contaminants that have been identified in sediments, water, and biota of aquatic systems in recent years have not resulted from point source or local releases. Rather, they appear to have originated at considerable distances from the affected system and have been transported through the atmosphere, often for hundreds of kilometres, before being deposited into aquatic ecosystems.

Acid rain is only one -- if the best known -- component of the LRTAP (long-range transport of airborne pollution) problem. Organic contaminants such as pesticides, products of the burning of fossil fuels, and polychlorinated biphenyls (PCBs) are dispersed great distances through the atmosphere, as are metals such as mercury, lead, and zinc. Recently LRTAP has been dramatically and tragically illustrated. The Chernobyl nuclear accident has resulted in radioactive contamination of wildlife and water bodies in the Nordic countries. Reindeer, sheep, and cattle meat are unfit for human consumption, and the chronic radiation effects on biota have yet to be determined.

The subtle nature of the build up of "toxic fallout," coupled with the fact that air masses carrying the toxic materials recognize no political or geographical boundaries, makes the study of their effects on water bodies both challenging and complex. Controls are often frustrated by the absence of proof of harmful effects and by the absence of an enforceable legal process.

This paper, one of a series of four discussion papers issued by the Science Council's Committee on Water Resources, examines the pathways and the effects or anticipated effects of LRTAP on freshwater systems in Canada. The author reviews the research to date, assesses the value of the application of lime to neutralize acidified lakes and rivers, and proposes directions for research and management.

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1. INTRODUCTION

Rationale and Objectives

The atmosphere receives and conveys a great variety of gaseous and particulate materials from many sources. Some of these materials travel considerable distances before they enter surface waters. Once in water, they can alter its quality, often to its detriment. Examples of this phenomenon include acidic deposition; "toxic fallout," whereby trace organics such as pesticides or PCBs (polychlorinated biphenyls) from distant sources are deposited in water bodies; elevated mercury in fish from remote lakes; and a recent dramatic example, contaminated water, fish, and sediments in Scandinavia due to radioactive fallout from the Chernobyl nuclear accident.

Because of the complexities of the pathways of airborne materials from source to water and the frequently non-acute or unknown effects of these traces of materials, solutions to the problems require research and synthesis of information from a variety of disciplines, including physics, chemistry, meteorology, geography, geology, limnology, hydrology, ecology, toxicology, physiology, and engineering technology. The ecosystem approach, which draws on geochemistry, hydrology, and terrestrial and aquatic biology, is almost essential because of the intimate connection between a water body and its watershed.

There is no shortage of information and there is a reasonable degree of understanding of the processes involved. The challenge is to synthesize the data and make reasonable predictions about effects. In some instances the damage is done, but rehabilitation is feasible if scientific data can be integrated sufficiently to support technological solutions. In other instances, water bodies are threatened, but have not yet shown permanent changes, at least according to the obvious indicators. In such instances the need for a predictive approach is clear.

From the point of view of water policy, any approach that is not interdisciplinary will have limited success. Policy decisions should be based on models that incorporate physical sciences, economics, and sociology.

This essay sets out research needs for Canada, based on the literature, ongoing research, and the opinions of concerned professionals. The subject is limited to contaminants that travel some distance through the atmosphere. Apart from references to smelter studies in the spatial comparisons and in the section on mitigation of acidification, I did not look at the point-source effects of air pollutants on water.

Economic considerations are not addressed in detail, although general concern is expressed for recent cuts in research budgets, especially at the federal level. During the preparation of this discussion paper I received a notice from the director general, Inland Waters and Lands Directorate, that included the following message: "As part of the restraint measures implemented by the federal government to reduce expenditures, the 1987-88 Water Resources Research Support Program has been cancelled." This small program, of some $0.25 million, supported individuals doing water-related research at Canadian universities. Its cancellation is but one example of the fiscal problems that researchers face. More details of how water-related research is funded are provided in the Pearse report.[1] It is clear from the report that in many areas of water research, especially in water quality management and protection and environmental management and protection, funding increased between 1966 and 1983.

Problem Definition and Areas of Uncertainty

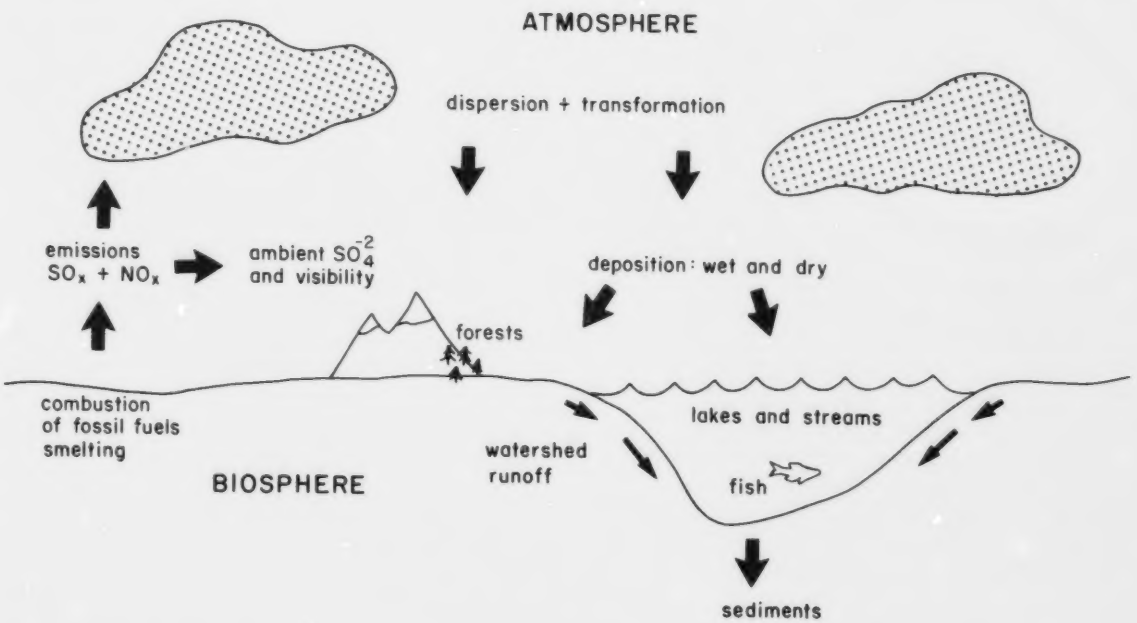
A great variety of chemical compounds fall into the category of air pollutants, which can be separated into a) air pollutants that result from the perturbation of natural cycles and b) artificial chemicals, which are often persistent. In the first category are the oxides of sulphur and nitrogen, the precursors of acidic precipitation, as well

as metals such as lead and mercury, and nutrients such as phosphates, simple carbon compounds, and simple nitrogen compounds. In the second category are many pesticides, and PCBs.

For any of these materials to be transported over long distances through the atmosphere, they must be in gaseous or fine particulate form. For the most part they enter the atmosphere from a stationary (for example, a power plant, metal smelter, or incinerator) or moving (for example, an automobile) combustion source. In the 1960s and 1970s concern for local air quality in urban and industrial centres led to construction of new power plants and smelting complexes with taller stacks. Local air quality improved, but in the absence of controls on emissions, contaminants simply dispersed over greater distances. Industries were not entirely responsible for this short-sighted solution; environmentalists often supported the "dilution" solution. Other contaminants disperse in the atmosphere during normal use. For example, pesticides are deliberately sprayed over large areas.

Awareness of the phenomenon of "acid rain" dawned in parts of Scandinavia in the late 1960s.[2] By the mid 1970s, when the first International Symposium on Acid Precipitation was held in 1975,[3] scientists in Europe and North America were recognizing the extent of acidic deposition. Figure 1 summarizes the major pathways and transformations of acidic material from source to receptor.

Figure 1. The Major Pathways and Transformations of Acidic Gases that Result in the Deposition of Acidic Material onto the Ecosystem



The definition of the effects of acidic deposition is difficult. The receptor, usually a living system or human being, may be entirely unaffected or affected in a manner that cannot be measured over the short term. Another problem is our poor ability to measure relationships between the source of emissions and the fallout of the emitted material (the deposition) onto the receiving system. This is not suprising because atmospheric transport and transformation of pollutants is affected by a number of unpredictable factors, such as the weather. In the so-called target loading study,[4] scientists were unable to state with certainty that a 30 per cent (or 50 per cent) reduction in emissions of sulphur would protect the most sensitive ecosystems. Nor can experts be certain that the relationship between emission and deposition of sulphur is not linear, although this has been argued. Furthermore, the quantitative relationship between deposition of material into an aquatic system and the biological effects is not completely predictable.

The acidity of rainfall is measured on a logarithmic scale called pH (Figure 2). Lakes and streams vary greatly in their sensitivity to acid inputs, as illustrated in Figure 3. A large productive lake in a region of soft carbonate rocks is unlikely to acidify from low pH rain, whereas a small softwater unproductive (oligotrophic) lake on nonsoluble bedrock such as granite is extremely sensitive and has little capacity to buffer acid. When protection of water bodies from acidication is considered, it is the most sensitive regions that have to be given priority. For Canada this means the water and soils on the Precambrian Shield, rather than the Great Lakes. It means mainly the lakes and rivers in Ontario, Quebec, and Nova Scotia rather than those in the western provinces.

Effects and potential effects of acidification on aquatic organisms, especially fish, have been described in great detail.[5] For the most part, the changes are detrimental in that with increased acidity desirable fish species are lost, and richness (diversity) of species eventually decreases. Many species cannot live at low pH (Figure 4). The aquatic system, being simplified, becomes more vulnerable to disruption, and ugly mats of algae often occur.[6] Although each aquatic system is unique, the general trend of biological response to acidification is similar in all geographic regions affected.

Over the past five years or so, it has become apparent that acid precursors are only one component of the acidic deposition problem. Polluted rain, even in areas remote from sources, contains traces of metals such as zinc, lead, and mercury, as well as persistent organics such as chlorinated hydrocarbon pesticides, polychlorinated biphenyls (PCBs), and polynuclear aromatic hydrocarbons (PAHs). Recent studies of acidic deposition have begun to address these other trace contaminants as well as acid precursors.[7] Already it has been proposed that the toxic effects of trace contaminants such as organics may be enhanced at low pH.[8]

Even though traces of metals and organics enter water bodies from the atmosphere,[9] and even though additional metals may be dissolved out of soils, rocks, and sediments by acidic water,[10] it is still questionable whether direct or indirect effects on aquatic biota or on human beings result from these additions. Because the materials are present in trace amounts (parts-per-trillion or lower) and because many different contaminants are added as mixtures to our water bodies, their respective effects, be they toxicity, stimulation, carcinogenicity, or teratogenicity, can rarely be determined from field studies or surveys. And even when abnormalities start to show up in biota, as for example with fish from polluted water showing tumours,[11] it is very difficult to relate a symptom to a specific chemical.

There is no question that the overall contaminant burden of many aquatic systems is increasing. Although surface waters may show some elevation over historical levels of acidity or trace metals and organics, a much more dramatic signal comes from sediments at the bottom of lakes. Sediments are deposited continuously, and along with additions of natural inorganic and organic

Figure 2. The pH Scale

Legend

The diagram shows some "bench marks" for the pH of different materials. Clean rain has a natural pH of 5.6; this is slightly lower than neutral (pH 7), because of the presence of carbon dioxide, which dissolves in water to produce a weak acid.

The pH scale is logarithmic, that is, a change in one unit means a 10-fold increase in acidity. The scale is also based on negative logarithms, so that the lower the pH value, the greater the acidity.

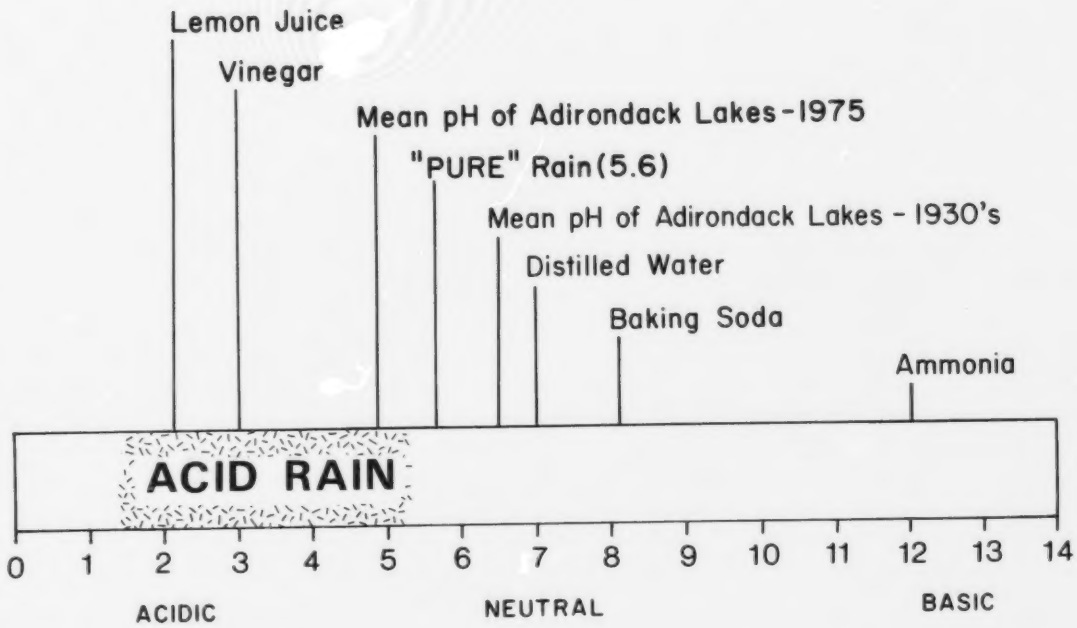


Figure 3. Waters of Differing Buffering Capacities

Legend

The diagram illustrates waters of differing "buffering capacity," or ability to receive acidity without changing pH. The most well-buffered (line A) hardly shows any drop in pH after addition of acid, while the most poorly buffered (line D) drops rapidly in pH as acid is added. Other waters lie somewhere in between. Line A would be typical of hardwater over limestone bedrock or carbonate rich soils; line D would be typical of a soft water shield lake on granitic bedrock and poorly developed acidic soil.

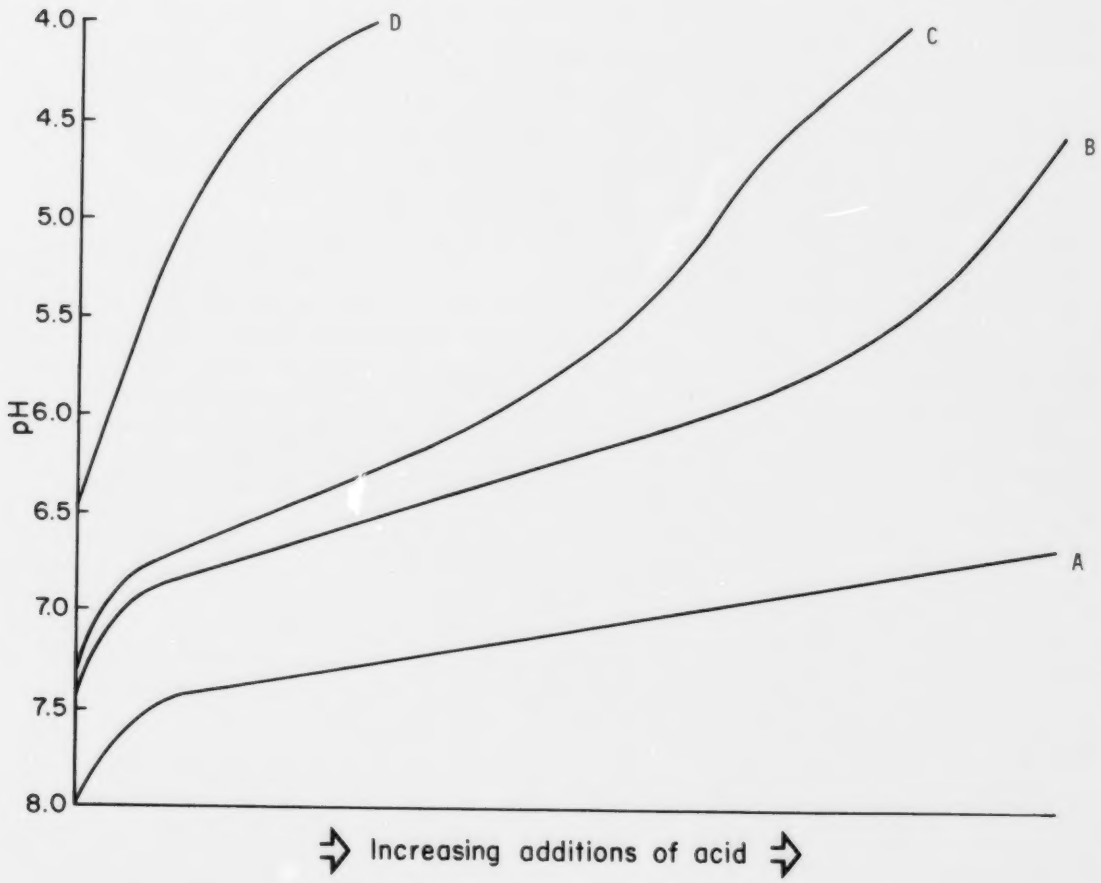
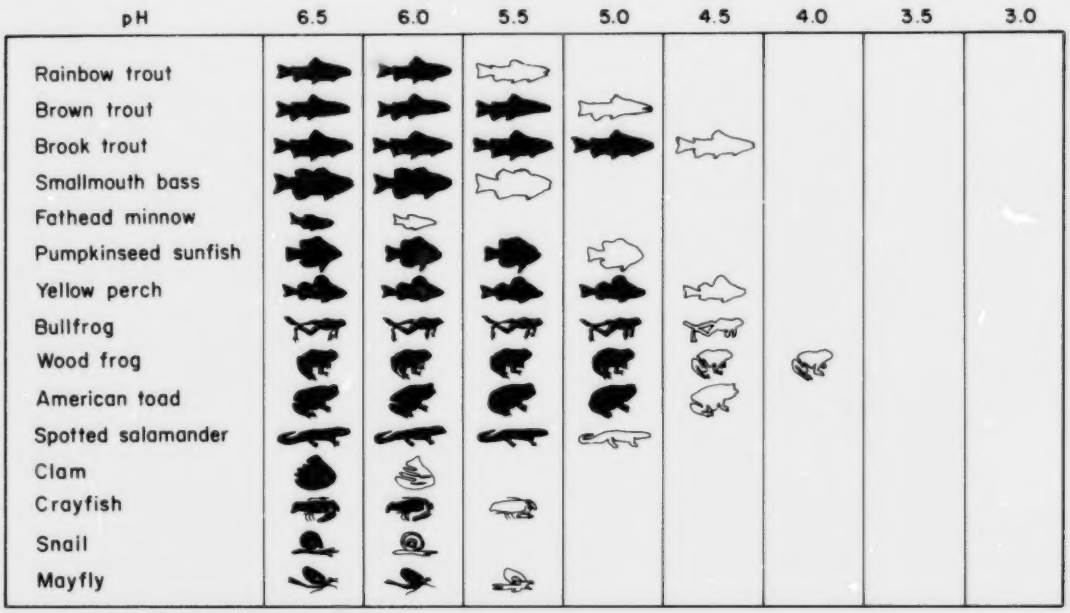


Figure 4. Sensitivity of Aquatic Biota to Low pH. The solid black indicates "normal" animals whereas the white indicates survival but with impaired functions.



material, contaminants, which adhere to particles or which are insoluble and form precipitates, are also deposited. A fairly sophisticated branch of geochemistry has developed as part of paleolimnology, in which historical records of chemicals added to lakes are reconstructed from lake sediments by careful coring and subsequent chemical analysis of sequential layers. It is not appropriate here to discuss the assumptions and technical problems of the method, but with all its limitations, this geochemical approach, combined with examination of biological remains in sediments, is a powerful one. It has provided strong evidence for increases over the past 50-100 years in the burdens of metals such as lead, zinc, and cadmium, as well as clear profiles for increases of persistent organics, in lake sediments. As well as providing this historical evidence, that is, being useful as a diagnostic tool, the sediments represent a major problem as well. Sediments contain much higher concentrations of contaminants than the overlying water, and this causes concern in two areas. Firstly, the organisms that live in sediments are exposed to higher concentrations of contaminants and may be damaged or introduce contaminants into the food chain from this source.[12] Secondly, the material in sediments may be released back into the water, providing an internal source of contaminants even after new inputs have ceased.[13] Any disturbance such as dredging can enhance this tendency. The extent to which sediments form a "reservoir" rather than a "sink" for contaminants is very sparsely understood.

The acids and trace contaminants that fall into our water bodies rarely carry a "fingerprint" of their respective origins. In general they are ubiquitous contaminants, and their transportation medium, the atmosphere, does not recognize geographical, much less political or national boundaries. The uncertainty concerning origin, added to the uncertainties concerning harmful effects and quantitative source-receptor relationships, has resulted in delays in the implementation

of clean-up operations at the source. The international nature of the respective Europe-Scandinavia and United States-Canada (and now United States-Mexico) transboundary pollution has given the decision making process a high profile politically. Although scientists in the United States and Canada for the most part agree that there is "compelling circumstantial evidence" of damage to aquatic ecosystems from the long-range transport of airborne pollutants, action to control the source has been slow. In part as a consequence of this, treatment of at least one of the symptoms, acidification, has been investigated concurrently with attempts to cure the "disease."

> At the heart of the acid rain problem is a complex and rapidly evolving body of research which suggests that the environmental impacts of acid deposition could be devastating, yet provides a frustratingly incomplete picture of the actual process through which pollution from specific sources leads ultimately to ecological damage.[14]

Table 1 summarizes the problems and uncertainties introduced in this chapter.

Table 1. Issues, Concerns, and Uncertainties Related to Aquatic Ecosystems and Airborne Contaminants

Issues	Problem/Uncertainty	Remedy	Comment
1. Gaseous and particulate materials (pollutants) emitted from combustion sources. Pollutants include oxides of sulphur and nitrogen, metals and organics, also nutrients.	Inadequate control at source; for most part technology is available but implementation has socioeconomic cost.	Implement controls.	Problem is in great part a social, political, or economic one.
2. Sources are increasingly from tall stacks or from processes designed to spread material over large areas (sprays).	Materials travel great distances (1000s of km) from their source and are deposited in precipitation.	Implement controls or eliminate sources.	Remedies claimed to be socioeconomically extremely problematic.
	The relationship between source (emission) and deposition of sulphur and nitrogen oxides is not linear especially based on European data. But nonlinearity is not strong in North American data.	Obtain improved measurements and better understanding of physical and chemical processes involved in atmospheric processes of sulphur and nitrogen oxides. Validation of models.	At present there is great reliance on models. Modelling studies should be continued, but not at the expense of empirical observations in the field. Eventually models should become more realistic.
3. Pollutants of concern have multiple sources.	Source identification is sometimes difficult, therefore clear "proof" of the polluter may be lacking.	Experimental "seeding" of major sources with unusual substances can assist in tracing the source. Other fingerprints such as isotopic ratios of sulphur may be diagnostic.	In most cases, this is not perceived by scientists to be a major problem in the context of abatement.
4. Many substances other than acids are deposited with acidic deposition. The effects of the pollutants on biota are imperfectly understood; the relationship between deposition and aquatic effects is nonlinear and site-specific.	For acidic materials, the effects are rather clearly documented, even though mechanisms are less clear. Quantitative relationships are not predictable. For trace metals and organics there is increasing uncertainty concerning their acute or chronic effects.	Models may never be satisfactory in this area. Since the materials are for the most part known to have the potential for harmful effects on living systems, a risk assessment approach to contaminants in water is the most responsible course. Early warning signs using biological indicators and monitors can prove to be useful.	If we wait for massive effects or absolute proof, of damage, it may be too late to reverse the effect.

Table 1. Issues, Concerns, and Uncertainties Related to Aquatic Ecosystems and Airborne Contaminants (continued)

Issues	Problem/Uncertainty	Remedy	Comment
5. For aquatic systems, most acidification seems to result from sulphuric acid; nitric acid is believed to be retained in the terrestrial system.	Reduction of sulphur-containing emissions has been the goal for stationary sources in relation to acidification of aquatic systems; we may be overlooking an important component. The removal of nitrogen oxides from power plants is not technically as advanced as the removal of sulphur oxides.	Continue to monitor the balance of both types of acids especially in the calibrated watershed areas. Look for effects where nitric acid is the major major atmospheric pollutant.	The problem may be academic, since terrestrial systems may be showing effects from nitric acid, and if so, nitrogen oxides will be addressed for a different reason.
6. Sediments reflect regional as well as local deposition of contaminants. Sediments contain higher concentrations of contaminants than overlying waters, and they are relatively permanent or "in-place" pollutants.	It is unclear whether sediments represent a sink or a source of pollutants.	Monitor by chemical and biological methods the fate of in-place pollutants in sediments. If necessary, immobilize or remove sediments, or limit the use of the affected water bodies.	Major area of concern. Remedies are almost entirely unsatisfactory or impractical at present.
7. Should affected or threatened waters be treated?	There are ethical and philosophical objections to treating acidified waters, but technically, it is possible to neutralize acid waters and improve fishery.	Research on management on reclamation, liming or other treatment should not be at the expense of or an alternative to treatment of the problem at source.	Public demand, requires that some attempts will be made to lime acid waters. It makes sense to approach this scientifically, and probably to lime a limited number of lakes.

History of Major Studies in Canada and the United States

The first International Symposium on Acid Precipitation and the Forest Ecosystem was held at Ohio State University in 1975.[15] A workshop, organized as a follow-up to the symposium, included a panel on "Effects on Aquatic Systems." The workshop recommended in its report[16] that researchers

- search for literature about hydrogen ion effects on aquatic organisms
- establish permanent networks for monitoring precipitation chemistry
- develop criteria and establish networks for monitoring volume discharges, chemistry, and biology of freshwater systems
- conduct in-depth studies of hydrological, chemical, and biological interrelationships in aquatic systems with respect to small and large accretions of acids, heavy metals, and nutrient ions in precipitation
- establish sites for experimental work on watersheds that contain lakes and streams.

Most of these recommendations are being implemented in various parts of the globe where acidic deposition is of concern, even in the tropics and in the southern hemisphere. The impetus behind some initiatives is difficult to identify with certainty. But certainly the work done in Europe, the dedication of a few scientists in Canada and the United States, and the Ohio conference made a major contribution to all of them. I confine myself to the North American scientific research and its contribution to policy. A great deal of work has been done in Scandinavia, especially Sweden and Norway, which is not referenced here.

Precipitation monitoring networks have been set up. In 1972 the European air pollution problem was brought to public attention when the Organization for Economic Co-operation and Development (OECD) program on Long-Range Transport of Air Pollutants (LRTAP), in which Canada participated, was set up. Our own Canadian Network for Sampling Precipitation (CANSAP), which began in 1976, operates 50 stations across Canada. Whelpdale (Appendix A) pointed out that CANSAP grew out of awareness in Canada of the acid deposition phenomenon, due to early warnings from the World Meteorological Society (WMO) Background Air Pollution Monitoring Network (BAPMON), which began operating in 1972.

Similarly the United States set up its National Atmospheric Deposition Program (NADP), due in no small part to the efforts of two scientists, Cowling and Likens (Whelpdale, Appendix A). The 1975 Ohio symposium provided a stimulus to developments.

Techniques for sampling and analysis have evolved and improved over the last 12 years, sometimes making between yearly comparisons of data difficult. Theoretical models of atmospheric transport of pollutants include the Acid Deposition and Oxidant Model (ADOM), jointly sponsored by Environment Canada's Atmospheric Environment Service (AES), the Ontario Ministry of the Environment (OMOE) and the Federal Republic of Germany; and the Regional Acid Deposition Model (RADM) built by the University Corporation for Atmospheric Research in Colorado (UCAR) and funded by the U.S. Environmental Protection Agency (EPA). Both ADOM and RADM are complex eulerian models that require state-of-the-art large computers. Earlier linear models are still in use. None of the existing models produces reliable estimates of spatial and temporal distribution of acidity, much less of the trace contaminants. In 1983 the Atmospheric Transport Committee noted insufficient confidence in the available models to recommend their use for making decisions on control strategies.[17]

With respect to the other recommendations of the 1975 Ohio workshop, the "calibrated watershed approach" has been applied to at least six sites in Canada. This approach calls for actual measurements of imports, exports, and retention of chemicals in a

lake and its watershed. Long-term detailed monitoring of chemical budgets and biological data collection in these areas, chosen to represent respectively severely impacted and less threatened regions in terms of pH of precipitation, should be invaluable. Only recently, however, have data for trace metals been collected with any degree of reliability, and there are no routine measurements for the trace organics in air, precipitation, or receiving systems. This is for reasons of technical limitation and cost, rather than for lack of scientific rationale. A recent report on the Great Lakes[18] pointed out that 80 per cent of the PCBs entering Lake Superior come from the atmosphere. Subsequently, additional data that demonstrated the need for careful monitoring of trace contaminants in precipitation were presented at the 1986 International Joint Commission (IJC) workshop.[19]

Another recommendation of the Ohio workshop was for experimental work on whole systems. Experimental manipulation of a whole system, for example, an entire lake, can provide a perspective on the ecological effects of acidification that is different from that obtained from experimental studies in the laboratory. Experimental acidification of whole lake systems has been done and continues in Canada and more recently in the United States.[20]

Since 1975 the response of the scientific communities and the funding agencies in Scandinavia, mainland Europe, the United Kingdom, the United States, and Canada have been nothing short of remarkable. The second international conference on Ecological Impact of Acid Precipitation was held in Norway in 1980, and in 1985 the international "Muskoka Conference" was held in Canada.[21] In addition to the proceedings of these large conferences, several major documents have been produced in North America. These include the Atmosphere-Biosphere (A-B) report of 1981,[22] a report that touched off discussion on the "target loading" issue. The A-B report referred to the desirability of pH of no lower than 4.6-4.7 in precipitation, which would require a 50 per cent reduction of deposited hydrogen ions. This conclusion was misinterpreted by the press as a call for 50 per cent reduction in emissions. In fact, the A-B report did not put a number on the reduction of emissions that would be needed to meet the goal. Following this confusion, the Committee on Atmospheric Transport and Chemical Transformation in Acid Precipitation was formed, and in 1983 published their review of scientific understanding of atmospheric processes in eastern North America.[23]

In addition to the A-B report, 1981 saw the release of the Canadian Associate Committee on Scientific Criteria for Environmental Quality's report on "Acidification in the Canadian Aquatic Environment."[24] This publication was part of the National Research Council of Canada's series of independent scientific reviews of environmental criteria, a series that has now been terminated by removal of its budget. Also in 1981 the Canada-U.S. Memorandum of Intent (MOI) interim reports were released. The final reports were made in 1983. These documents were prepared by government work groups, to fulfil a requirement of the Memorandum of Intent on Transboundary Air Pollution, which was signed between Canada and the United States in August 1980. Unfortunately these MOI documents appeared to have little direct political or other impact when they were released, even though both Canada and the United States provided peer reviews that were also published. It is difficult, however, to measure the impact of this type of work; perhaps its very existence has an impact or stimulates more effort.

Also in 1981 The Canadian Coalition on Acid Rain, a nationally funded lobbying group, was initiated. It still exists, but in a recent interview[25] Hurley is reported as saying that the coalition has largely achieved what it set out to do. Certainly, provincial governments in Ontario and Quebec have recently started to enforce reduction of emissions of sulphur oxides (Appendix C) and Manitoba is expected to follow suit. This contrasts with the lack of action in the United States, where no major breakthroughs in terms of emission controls have occurred to date and the government continues to fund

research rather than legislate or even recommend emission controls, claiming that it needs more information before controls can be justified. The coalition had the advantages of a message that is easy to understand and intense media coverage.

By 1981 it was increasingly recognized that precipitation contains contaminants other than acid precursors. The concept of "polluted rain" could be the subject for a future public education campaign.

The political struggle for recognition of the need for controls of atmospheric emissions on both sides of the Canada-U.S. border appears to have been one of the incentives for a recent investigation of trends in acid deposition organized by the U.S. National Research Council.[26] The Council's 1986 report known as the Trend Assessment Study notes that it is difficult to "prove" that precipitation has become more acidic and polluted over recent decades because of the lack of good historical data. It cites alternative explanations that have been offered, in the absence of strong time-trend data for both chemical changes and biological effects, to account for "every proposed link between the deposition of airborne chemicals and an adverse environmental effect."[27] The study addressed trends in emission of sulphur and nitrogen oxides; precipitation chemistry; atmospheric sulphates and visibility; surface water chemistry; sediment chemistry and diatom remains; fish populations, and tree (growth) rings.

Since the MOI there have been comprehensive assessments of progress in acid rain research in Canada and in the United States. In 1984 the Canadian Federal/Provincial Acid Rain Research and Monitoring Coordinating Committee (RMCC) and the U.S. National Acid Precipitation Asssessment Program (NAPAP) undertook assessments. The RMCC published a report in 1986 that includes important new information from the 1985 "Muskoka Conference."[28] Some of its conclusions deal with aquatic systems.

1. Decreases in sulphur flux through certain aquatic systems since the mid 1970s have been associated with increases in pH and alkalinity of surface waters, that is, there is some recovery in terms of water chemistry.
2. Shallow groundwater showed acidification and increased levels of sulphate. This is the first evidence of the phenomenon in Canada.
3. Certain process models relating deposition of airborne material to changes in aquatic chemistry have been validated on a watershed scale and for short periods. Episodic events have been accurately simulated but long-term modelling has been less successful.
4. Loss of fish populations over time has only been shown clearly in a few regions of Canada, although the correlation between loss of species and low pH continues to be documented from spatial surveys. Recent evidence shows some recovery of fish populations coincident with reduced sulphate deposition and improved lake water quality, that is, there is evidence of biological recovery.
5. Many aquatic organisms other than fish show toxic effects and decline of populations as acidity and aluminum increase. The other organisms include algae, zooplankton, amphibians, and waterfowl.
6. The rate of response to decreased acidic loadings appears to be fairly rapid (years rather than decades) but precise quantitative data on chemistry for rate of response are "limited." For biological response the rate remains "poorly defined," but clearly recovery is impossible once species have been extinguished.
7. The potential consequences of mitigative measures continue to be investigated.
8. "Limited surface water surveys" have produced estimates that approximately 14 000 Canadian lakes are already acidified (a pH of 5.0 or less). With the current annual deposition rate of 20 mg/ha of wet sulphate, mathematical predictions show that a further 10 000-40 000 lakes will eventually be acidified.
9. Models for target loading suggest that reduction to an annual rate of 12 mg/ha of total sulphate may be required to prevent damage to highly or even moderately sensitive lakes and rivers.

Approaches to Research on Airborne Contaminants and Aquatic Systems

Several approaches have already been referred to in the preceding section. Although a distinction is made between research and ongoing monitoring or management, this distinction is felt by many to be unrealistic and even misleading. It is used here for convenience, but monitoring as research will be addressed in chapter 4.

The earliest approach in research on airborne contaminants and aquatic systems was descriptive or observational and consisted of synoptic or seasonal surveys of chemical and biological features related to lake acidification. The phase of documenting the range of effects that low pH and correlated variables can have on biota is about over. Mechanisms remain incompletely understood and now different types of research are required.

The 1986 U.S. National Research Council document[29] looked at time trends. Series of measurements over time are rarely available and are not usually of sufficient quality or consistency to be useful, not only because of technical advances in making measurements, but also because scientists become more skilful. For example, standard instruments to measure hydrogen ion concentration were inadequate, even 30 years ago, to measure pH of soft low conductance (dilute) waters and the very limited colorimetric methods were used. Furthermore, as scientists have studied the chemistry of acidic waters, they have improved their sampling and storage techniques and are more aware of sources of error.

More common and useful than most historical datasets are the indirect methods of paleoecology whereby historical reconstruction can be made from lake sediments, tree rings, permanent ice and snow caps, and plant material in the form of peat. Even anecdotes and information from records kept by volunteers cannot be entirely discounted. Loss of fish populations in Norway was consistently documented by nonscientific members of the general public, who kept records of fish catches over time.

Another possible approach is experimentation. Design, replication, and reproducibility all have to be considered. Because the physical and chemical mechanisms and the biological responses to acidification are complex, large experiments are more realistic than small ones. They are not always practical in terms of cost and logistics. Experimental work on acidification of aquatic systems has ranged from simple laboratory bioassays where acute responses to acidity are measured, through chronic tests, to manipulations of microcosms (model ecosystems), limnocorrals (enclosures or columns in lakes), or whole lakes.[30] Results from whole lake acidification are invaluable in improving our understanding, especially of community response and system-level response, and have provided insight into the functioning of aquatic ecosystems. Large-scale manipulations also show promise in terms of predicting the reversibility or potential for mitigation of the acidification of surface waters. This is discussed in more detail in chapter 3. The simpler laboratory studies tend to reveal physiological responses of organisms rather than allow prediction of future effects of acidification on whole systems.

Simulation models -- from simple ones of single populations to complex representations of global circulation of atmospheric components -- have also received a great deal of attention. One of the major practical goals of models is to give us more predictive power. With all their limitations and simplifications, models have a contribution to make, especially where large-scale experiments would be too time-consuming or costly, or are not technically feasible. Models are particularly useful for studies of atmospheric transport and transformation. Limitations are discussed in a number of reports and reviews, including the Calvert Report.[31]

Monitoring and Management Studies

Good quality monitoring networks at all stages of the source to receptor train are essential to spot problems and to assemble data bases to improve the predictive value of models. Most routine monitoring to date

has been for chemical components especially major anions and cations (sulphate, nitrate chloride, calcium, magnesium, hydrogen and others). When integrated, as in the calibrated watershed approach (where a number of parameters are measured concurrently in a planned design, and the measurements continue through time), monitoring data are more than descriptive information and can be used in mechanistic and modelling exercises.

Biological monitoring uses the response of organisms to detect fluctuations in the state of the environment. The response can be at any level, from the biochemical, to that of the population or community. The diatoms that are used for historical trend analysis, being sensitive to different levels of acidity, exemplify the biological indicator approach. The ideal biological monitor would provide an early warning: ideally it should not be a "valuable" species from a management point of view nor a key species from an ecosystem point of view.

Even more fundamental than the need for monitoring is the need for inventories of resources and of chemical properties of surface waters. In the United States, there are provisions for National Surface Water Surveys (NSWS) in various regions of the country. One major objective is to describe in a fairly small-scale grid the sensitivity of surface waters to acidification. That will be followed by a biological inventory. Sampling protocol for the latter presents major problems. Even if funds were unlimited, biologists disagree concerning the most appropriate sampling procedures, measurements, and indicators to use. The United States survey involves several levels of review by outside experts, and should be state-of-the-art. Maps of surface water sensitivity, which incorporate geology and water chemistry, have been produced for major regions of the country.

In Canada the individual provinces have worked independently to prepare such inventories. Ontario's classification of lakes into five levels of sensitivity[32] has an obvious advantage in that it is simple and easily understood by the public.

Management tools beyond the various types of monitoring include the application of results of manipulation or experiments. In fact the rationale for manipulation is often to test a management option. The chemical neutralization of acidic waters (liming), discussed in chapter 3, is a good example of such manipulation.

3. MITIGATION OF SURFACE WATER ACIDIFICATION: TO LIME OR NOT TO LIME?

Background

A number of lakes and rivers in eastern North America are acidified or acid-stressed,[33] and for some systems acidic deposition is suspected or known to be the cause. Decrease of sulphur- and nitrogen-containing emissions has been proposed as a solution to the acid-loading problem. Technically, removal of sulphur oxides from stack gases is feasible. The use of low sulphur coal and the removal of sulphur from ore prior to smelting are also feasible options. Any of these solutions would increase costs at least in the short term. Quantitative predictions concerning the response by the receiving biota to decreased emissions are not terribly robust. Across-the-board abatement as a solution is not acceptable and is unlikely to be accepted in the near future by the United States government. The governments of Ontario and Quebec have begun to implement regulations to decrease sulphur emissions from the major stationary sources (smelters and coal-fired electricity generating stations) and Manitoba is moving in the same direction.[34] Canada, trailing the United States, is phasing in automobile emission controls, which will result in decreased oxides of nitrogen in automobile emissions. Oxides of nitrogen are still emitted from coal-fired power plants and the technology to remove these is less advanced than that to remove sulphur.[35]

In the absence of immediate abatement of emissions, treatment of the affected water bodies with chemical neutralizing agents (liming) is an alternative solution.

Recent History of Liming

The addition of alkaline substances to aquatic systems to neutralize acid conditions is not a new idea. Unproductive and acidic waters occur naturally, and for centuries agricultural lime has been used in Europe and North American to increase the productivity of small ponds. Since the 1920s Norwegians have used limestone filters, with considerable success, to raise the pH of fish hatchery waters.[36]

In the context of acidic deposition, Sweden has been the front runner in the chemical treatment of acid lakes. Starting in the late 1960s, and expanding in 1975-76 to the treatment of 1500 lakes per year, the government of Sweden has promoted and funded the liming of acid-stressed lakes. Commercial operations from Sweden (for example, cement companies) now produce brochures advertising their products' capacity to reverse acidification. Sweden began liming to protect fisheries and to improve conditions so that fish stocking would be successful. Hasselrot and Hultberg reported that "where acceptable water chemistry has been achieved, successful reproduction and recruitment of fish populations have occurred soon after treatment."[37] However, they did not define "acceptable water chemistry."[38] Additional objectives of the Swedish work in the 1970s were to evalute liming strategies and technologies for different aquatic ecosystems. Sweden was committed to liming 20 000 water bodies by the end of 1986.

New York State has some early examples of addition of lime to bog ponds (which are naturally acidic), where successes were for the most part short-lived when calcium hydroxide (slaked lime) was used. New York State also has a more recent history of liming using mixtures of calcium hydroxide and calcium carbonate, or sodium carbonate, on small lakes. The neutralizing effect was most successful in lakes with low flushing rates or lakes with no inlets. New York's policy is to continue liming a limited number of lakes in the 1980s, to protect "unique or extremely valuable aquatic resources."[39]

In Canada in the early 1970s a series of four lakes close to the Sudbury smelters were used in experimental neutralization and fertilization treatments.[40] Several other lakes were added to the program in the middle to late 1970s.[41] These lakes were extremely acidic with pHs as low as 4.5 and were also polluted with metals, especially copper and nickel, from the Sudbury smelter

emissions.[42] If a "worst case" were sought, this area was certainly a strong candidate. As a result of additions of calcium hydroxide and/or calcium carbonate, the pH, alkalinity, and hardness increased while dissolved metals decreased, presumably as a result of the decrease in solubility and resulting precipitation of metals into the sediments. A great deal of data were generated by these studies, some of which were applicable to the less extreme situation of [illegible]e acidification from the long-range tr[illegible]port of airborne pollutants and have b[illegible] used in recent studies. In the Sudbury whole lake experiments, fish that were stocked after liming did not survive, but the reason for their failure to survive was almost certainly metal toxicity from residual copper,[43] rather than low pH.

Other attempts by Ontario to protect fish from acidity were carried out in 1979.[44] The approach in Gunn and Keller's experiments was to protect fish eggs during spring thaw, when a pulse of acid tends to enter spawning areas during snow melt. For rainbow trout, the addition of crushed limestone to the spawning area was only moderately successful but for the less sensitive species of brook trout and lake trout, the survival of eggs and fry after crushed limestone treatments was much better.

In Nova Scotia salmon rivers have become acidified and salmon fisheries are being or have been degraded. Watt has proposed some original approaches to liming in this part of Canada and demonstrated their potential for success.[45] For example, the neutralizing agent can be spread on the surface of the snow to be released into the spawning areas at snow melt, the time that is most critical in terms of the chemical loading and in the life history of the fish.

Any approach has to be site-specific and may require a great deal of preparatory work. Liming, although technically feasible, has not become a routine commercial operation in Canada. Careful studies are underway to evaluate the short- and long-term prognosis.

Methods for Neutralization and Evaluation of Success

The method of application, the chemical form of the neutralizing agent, and the time and frequency of application can be varied. Although economic considerations may tip the scales, methods clearly have to "work," that is, to restore the chemical environment to a condition that will support the desirable biota. In practice this means protecting fish. Scientifically, other levels of biological organization and other trophic levels also need to be evaluated. Simpler life forms, such as bacteria, algae, and invertebrates, are often more responsive to chemical changes, providing advance warning of danger to fish. These organisms are not only useful as indicators or monitors: more important, they are also integral components of the ecosystem. Changes in rates of bacterial decomposition, changes in primary production, or shifts in species composition of fish food organisms can affect fish populations. Therefore the method of evaluation for liming needs to be more comprehensive than the determination of fishery improvement.

The method for application of large volumes of neutralizing material to lakes is determined initially by accessibility. Trucking and boat application are clearly only appropriate when road access is possible. For remote areas, application from an aeroplane is the only alternative. Direct addition of neutralizing agent to the surface water is the most common approach. For fast-flushing water bodies, this is less satisfactory than for lakes with long turnover times. Additions of lime to the feeding streams is an alternative strategy. The best prospect for long-term effects is liming of the watershed. This not only provides a more long-lasting input of the agent, but it can also protect the terrestrial ecosystem from the effects of acidification. The major objection to this approach is the extremely high cost. Treatment of localized areas such as spawning grounds is another approach used to protect eggs or young fish during snow melt but it

does little for the rest of the system. It can be used alone, if the entire system is not yet acidified, or in combination with whole lake neutralization, when it provides additional protection for fish at this critical stage.

For rivers, which require a continuous supply of neutralizing agent, different techniques are used. Limestone added to the stream bottom theoretically provides a slow release of neutralizing agent over time. But such material may be transported downstream by the river flow. Furthermore the limestone soon becomes coated with organic material and metal salts. During times of low flow, the stream bottom addition of limestone works quite well, but it is not satisfactory for fast flow periods. Mechanized and automated methods for additions of lime, for example, from silos, have been designed to neutralize streams. Another approach is to divert a stream through a container of neutralizing agent such as calcium carbonate. Clearly the cost of these treatments escalates as more sophistication is built in.

The most widely-used neutralizing agent is calcium carbonate ($CaCO_3$), called calcite. Alternatives include dolomite limestone, which is magnesium and calcium carbonate, calcium hydroxide, or calcium oxide. Calcite is available commercially, in different sized grains, relatively free from impurities, inexpensive and noncaustic. Unlike calcium hydroxide, its addition does not lead to rapid and extreme increases of pH.[46] The major disadvantage of calcite is its low solubility.

One inescapable conclusion is summarized by the Electric Power Research Institutes: "biological changes in response to liming are not entirely predictable."[47] This is due in part to the fact that initial pH has a great deal of influence on the effect of liming as does the chemistry and morphometry of the water body. This means that large-scale liming without preliminary research would involve a great deal of risk. Preliminary research is costly, but the decision to lime should not be made without it, on the basis of public pressure, and when undertaken the operation should be based on scientific as well as economic factors. Many scientists believe it is fortunate that large-scale liming has not yet been undertaken in Canada.

Ontario's Current Liming Program

In 1981 the Acid Precipitation in Ontario Study (APIOS), which involves the Ontario ministries of Environment and Natural Resources, initiated a feasibility study into liming an acid lake (one that had "lost" its lake trout fishery) and a threatened lake (one that had a lake trout fishery but which was acid-stressed). The objective of the study was to "assess the role of liming in the management of acid-stressed lakes."[48] It was recognized that "to use neutralization to protect all or most of Ontario's threatened lakes from acidic precipitation is impossible."[49] The rationale for the new Ontario study was to consider (a) interim mitigation, (b) the protection of gene pools (for example, fish) and (c) a response to public pressure to "do something."

The initial stages of the study, starting in 1981, involved careful selection of two lakes and the establishment of baseline information.[50] In general the results are encouraging. The previously acidic lake, named Bowland, was limed from pH 5.0 to over 6.5, and the existing yellow perch population showed increased survival. Bioassays of lake trout fry during spring snow melt showed improved survival. Other chemical parameters, including aluminum, showed corresponding improvement. The whole lake liming did not, however, protect the nearshore water beneath the ice from acid pulses during snow melt. Algal mats, characteristic of acid-stressed lakes, decreased in Bowland. The acid-stressed lake, Trout Lake, was limed from pH 6.0 to pH 6.5, and the results for fish bioassay in the spring melt were similar to those for Bowland, but somewhat more erratic. Existing fish populations in the acid-stressed lake did not show significant changes in response to liming. For a third lake, with chemistry intermediate between the previous two, shoal liming, not whole lake liming, was attempted.

In brief, many of the results of the new Ontario liming studies were positive, and

few detrimental effects were seen. Booth et al. emphasize, however, that "whole-lake liming does not necessarily protect the nearshore shallow zones of the lake where lake trout sac fry are found during spring melt."[51] The five-year study has been completed, and results continue to be interpreted and published. Further studies of liming are being promoted by APIOS.

The Opinions of Experts

In 1982 Wright published a note entitled "The Ethics of Liming."[52] In this paper, he draws an analogy with the phosphorus-eutrophication problem, where reduction in phosphorus-loading often led quite rapidly to improved water quality. But in some instances, he points out, reduction of phosphorus did not have the predicted effect. Just as the residual phosphorus in eutrophic lakes acted as an internal source, Wright suggests that there might be residual sulphate that would "bleed" out of the sediments and could delay recovery even after emissions and therefore loadings of sulphur were controlled. In short, he emphasizes that we cannot guarantee that reduction of emissions will "cure" the acidification problem. Nor can scientists quantify accurately the reduction in emissions that would be required to produce a specific amount of decrease in the acidity of receiving waters. These uncertainties have been used as justification to delay abatement regulations.

They have other implications. Because emission controls may not lead to total recovery, other forms of treatment can be justified. In earlier attempts, such as the Sudbury experiments in the early 1970s and some Swedish experiments, re-acidification followed quite rapidly after liming.[53] Wright says that treatment of the symptom by liming and treatment of the cause by reducing emissions are not mutually exclusive. He concludes, however, that "liming should not be permitted to be conducted at the expense of efforts to eliminate this major environmental problem."

In the course of my interviews with Canadians from various professions who are concerned with acidification of surface waters, there was little divergence of opinion on the subject of liming. Brydges[54] pointed out that public pressure accelerated, if not caused, Ontario's decision to conduct research on liming of lakes. Quebec has also initiated a liming program,[55] the results of which are not yet available. It has been argued that it is cheaper to lime than to undertake abatement, but Brydges strongly expresses the opinion that liming can be done without interfering with abatement; specifically he does not consider that Ontario's liming program will interfere with efforts to get abatement in the United States.

Grima (Appendix A), in contrast to Brydges, considers that liming may reduce public concern and obscure the need for "abatement" technology. He thinks liming is a worthwhile experiment, but not adequate to be a policy response to sulphur dioxide loading.

Brydges, in a more recent discussion (Appendix A) cites the example of Sweden where liming is "the only alternative" available, because until further international action takes place, liming is better than allowing lakes and rivers to become or remain devoid of fish. Brydges also comments on the favourable local public reaction to recent liming experiments in Ontario, in contrast to those in Sudbury in the early 1970s, when the public objected to symptomatic treatment. Whelpdale (Appendix A) cautions that successful liming may give the false impression that the problem is being solved.

Elder (Appendix A) also emphasizes that "liming cannot be a substitute for control of emission of acid forming gases." One of the reasons for this is the vast extent of sensitive water resources in Canada and their remoteness, which means that extensive liming is simply not feasible. Whelpdale (Appendix A) also points out the scale of the problem, and adds the point that "frequent attention and repeated doses" of lime may be required, so that the technique is limited to very small-scale operations.

There seems to be little disagreement that with sufficient care, liming can be successful technically. But what does success mean? Liming does not automatically restore a lake to its former state. And fisheries management organizations, particularly in Ontario, have not been supportive of liming programs, because "modification of fish habitat is contrary to their policy of fish management" (Brydges, Appendix A).

Keating (Appendix A) agrees that, even given the most rapid pollution control imaginable, liming selected lakes and streams may be needed as a stopgap measure to protecting fish populations. The critical time for this has been estimated (OMOE, Brydges, Keating) as between 1990 and 1995.

Methods for Collecting Material

As part of the Science Council's study, "Water Policy: Toward the Year 2020," I interviewed experts in water, especially acid rain research and policy, early in 1987 (see Appendix A). I compiled my questions (Appendix B) using the papers from the Science Council's November 1986 workshop on water use and management. The names of other persons who have assisted me (perhaps unknowingly) by their comments, their responses to questions, and replies to my illegible memos, also appear in Appendix A. I have not attempted to attribute every comment or statement to an individual, but I have shown the final product to the main interviewees.

The Respective Roles of Governments and Universities in Water-Related Research and Monitoring

The most "broad-minded" response to the question of government and university roles came from several different government scientists who favoured an integrated approach, with joint research projects between government and university scientists, making government laboratory facilities, boats, and so on available to the often less well-endowed universities, and promoting more interaction than now exists. The devices of shared and adjunct appointments at universities for government scientists and sabbatical leave exchanges in either direction were mentioned favourably. Such cross appointment does occur to a limited extent, but is usually based upon arrangements between individuals and is not unreservedly supported by universities and university departments. One arrangement that was cited as ideal was that of the National Center for Atmospheric Research in Colorado (NCAR). NCAR is sponsored by the U.S. National Science Foundation (NSF), and staffed in part by university secondments of less than five years. Several government scientists pointed out that institutionally government departments tended to resist formal exchanges; university scientists (most of whom were not as enthusiastic about the exchange concept) were concerned about the mandate and the political limitation of government scientists, especially when working in "sensitive" areas. Again and again personal associations and friendships were mentioned as the current mode of interaction. There was some feeling that liaison in this area should be part of the university's and the government's formal mandates.

The models of how the university and government researchers should mesh must be based on the perceived role of the two groups. One university social scientist made the point that there should be a balance between accountability and creativity. In this model, research, planning, and monitoring could all be considered as components of a single problem-solving process, with a strong emphasis on creativity in universities and accountability in government, because government has to reflect on-going political priorities and mandates.

Further opinions on the respective roles included the observation that government could make more "long-term" commitments with good continuity of staff, whereas universities tended to have much of the work done as graduate student projects, which were of limited duration; this meant that universities could take smaller "bites" but could make more detailed studies. There was universal agreement that university research could be more flexible, more free. One university researcher remarked that "the closer research is to politicians and senior civil servants, the less free it is." The same professor considered that universities are the best organizations to do "disinterested" research, but that their results should over the long-term be incorporated in or used by government to build policy. This model, which one could describe as the long-term sequential one, although not limiting interaction, is distinct from the "blending" model or the model with ongoing long-term government programs and short-term spin-off "bites" for universities. The sequential model was referred to by several interviewees, including those with no current position in either sector. One of these

"independents" had the opposite view to that referred to earlier with respect to continuity. This person felt that there was more continuity in universities. Even so one university science researcher suggested that scientists need to be more conscientious about seeing one problem to a conclusion before tackling a new one. All the "independents" stressed the freedom and opportunities for creativity and innovation in universities, with the government able to pick up and use the results and eventually include them in shaping policy or in design of routine monitoring. The political cycle was seen by some as a limiting time frame for government research. There was also a plea for university researchers to "speak out" more than is currently done.

All the interviewees referred to funding and funding problems: both university and government researchers deplored the attitude of government ministries that they "want to do it themselves" so that researchers at university get "the crumbs." Others felt, and this was more general, that fair competition for funds was healthy and desirable, and were fairly happy with the governments' and other agencies' methods of selecting and awarding research funds. Review of scientific material by non-scientists was deplored by one person. The funding situation of the federal Department of Environment was universally condemned.

Monitoring was perceived as an important component of research rather than as another type of activity, although there was little disagreement that long-term monitoring programs should be the responsibility of government, in part because of the policy implications. With the acid rain phenomenon in particular, the need for continuous records obtained by well-designed monitoring schemes and the need for inter-calibration and consistency of methodology have been demonstrated.

A supplementary question was asked about research on monitoring techniques. Mention was made of "fossilized" methods that continue to be used because they have always been used; on the other hand, with research into monitoring there is in some areas an "overabundance of new techniques," many of which do not come into practical or general use. Several requests were made for looking at biological indices or monitors, with further warnings about the need to ensure standardization of techniques. There was agreement that biological monitoring was more difficult than chemical, and that it had great value.

Broad-scale, even global, monitoring is going to be needed more and more in the future, and we should look at chemical, physical, and, if possible, biological monitoring in a global context. Some researchers made a plea for ecosystem level monitoring, already accepted in specific studies (for example, the Great Lakes studies), to become routine, but to date indicators of ecosystem "health" are not routine monitoring tools. Research into broad-scale monitoring needs to be consolidated and translated into a policy or at least some protocols. The best examples of broad-scale monitoring programs in the context of atmospheric deposition are the recently established precipitation networks.

How Research is Organized

There was considerable disagreement about how research should be organized. The questions of who should judge the effectiveness of research and what the criteria should be for successful research were never answered. Several respondents pointed to indirect benefits of research that could not be measured systematically. Respondents saw it as fair to judge university scientists on the basis of peer review and number of refereed publications, but that this was perhaps too restrictive a basis on which to judge government scientists on exchanges in university departments.

Institutions and organizations that were mentioned as models for Canadian research were NCAR, already referred to, the Canada Centre for Inland Waters (CCIW), and the Dorset Research Centre of the OMOE. At Dorset, where emphasis is on acid rain research, university researchers are welcomed, graduate students work, and government scientists have appointments at one or two Ontario universities. Most of the

success of Dorset in terms of integration is still the result of informal interactions and a great deal of good will.

The model of the U.S. National Academy of Sciences (NAS) "blue ribbon" committees was proposed as a good example for Canada to follow, even though we need to remind ourselves that the United States has 10 times the resources that Canada has. Several interviewees referred to recent enquiries and commissions taken on by the Royal Society of Canada (RSC). It is quite well known that several eminent and senior members of the scientific community hope that a role comparable to that of the NAS will develop for the RSC. The main difference between the RSC and the NAS is the funding, of which the RSC has none in place for running the various commissions and high level committees. For recent RSC studies, funding came from external, mostly federal but in some cases provincial sources.

For water resources specifically, a Canadian Water Research Advisory Board was advocated. This board would need funds in order to have "teeth." Cancellation in 1987 of the existing $0.25 million in discretionary federal funds for water research (referred to in chapter 1), was seen by several experts as "deplorable" and "demoralizing."

Another U.S. model with a different purpose, which was praised, was a scientific research and technology committee of Congress in the House of Representatives; this has some authority to oversee funding and evaluation of research at a high level. Lack of understanding of science in government committees evoked considerable concern. A recent initiative in the Canadian House of Commons is a series of information exchanges between politicians and scientists.

There was universal praise for the Canadian Natural Sciences and Engineering Research Council's (NSERC) approach, but two concerns were raised: the lack of tight definition of "strategic" research (did it have to be "applied" in the immediate sense, or did it include promising ideas with potential links to areas of national concern?); and the fact that innovative young researchers with few published papers may be disadvantaged by the NSERC and similar systems.

Another interviewee favoured the German institute model: a research centre with a broad but defined mandate and a committed budget with guarantee of resources over the long-term.

An institute built around outstanding people, internationally recognized as first class, is the kind of national "monument" that we need. Independent, government funded national institutes for basic as well as applied research were favoured by most people. In addition, some kind of academy (which could grow from the RSC), which would commission and fund enquiries and scientific reviews on major issues, was also strongly favoured. Management of science was felt to be weak and in need of trained personnel who understand what scientists are doing, and who are able to react effectively.

A standing committee of the House of Commons, specifically on water research, was proposed; the continuation and increase of the existing informal cross connections was seen as highly desirable. One interviewee cited the group that formed to work on restoration of the Black Creek in Toronto. Perhaps surprisingly, communication of science to the public (or lack of it) was not picked up as a problem. When specifically asked, one interviewee said that not all scientists need to be expert in communicating to the general public, but that someone (a manager?) has to do this. No one was critical of the media, but nor was there any enthusiastic appreciation, except from the leaders of citizen groups.

Everyone agreed that none of these arrangements would work without a major injection of funds and a guarantee of continuity that would also represent a "vote of confidence."

Priorities for Water-Related Research

In response to a general question about specific areas of research and ranking of priorities, some interviewees limited their

responses to the LRTAP problems; others used a much broader interpretation. Two people emphasized that priorities should be set; one suggested that a Canadian Environmental Council should set priorities for research. Another suggested that government research managers should decide.

Regarding the LRTAP problem, someone recommended that in order to quantify pathways and inputs, we need to know more about how to make precise measurements. It was also pointed out that we know much more about sulphur oxides than oxides of nitrogen, and that we should pay more attention to the effects and the control (if necessary) of oxides of nitrogen. Monitoring must continue. Gathering information on atmospheric contaminants other than acid precursors was identified as a priority for research. The build up of sedimented contaminants was mentioned as a serious concern by one person.

Moving into more general concerns about pollution, several people put sediment dredge guidelines and the absence of any specific culprit in causing sediment pollution as high priority issues. We are faced with large areas (and volumes) of contaminated sediment about which decisions have to be made: whether to dredge, and if so how to dispose of the dredging, or to leave sediments in place, treated or untreated. This problem and its connection with toxic waste disposal and dump sites was of concern to a number of interviewees.

Several suggestions were made on national issues to do with water resources. Two people pointed out that in eastern Canada water quality commanded attention; whereas in western Canada concerns were for quantity. The demand for water for energy-related projects was given high priority for research by at least five individuals (export of water and power was deplored). One person felt that toxic problems may be easier to solve than the problems caused by massive use of water in energy production. Quebec was singled out by two people as an example of promotion of hydroelectric power generation for economic gain, without adequate research on the environmental consequences.

There were three strong recommendations for research using the risk assessment approach. In many instances it was felt that we have enough data, and should turn our attention to assembling and interpreting, as well as improving our predictions by using the data in models. Interestingly, only one person specifically mentioned human health risk, but it was clearly implied in other calls for risk assessment. Only one person suggested cost-benefit analysis for airborne contaminants and their effects, and controls.

Research on global-scale processes, such as climatologists already do, and on the general process of environmental degradation combined with the tendency to "spread things from local to the whole biosphere" were explicitly recommended by two people. The eternal question of how to translate "solid" science into "good" policy was seen as the highest priority by one expert.

Thus the responses varied from specific to general, with emphasis ranging from technical to social and from strongly applied science to philosophical considerations. No consensus can be reached, but this was a small sample and there was no intention to do more than extract ideas and suggestions.

The Value of the Watershed as a Management Unit

Very little time was spent on this question, which came out of a recommendation of the Pearse report. Scientifically, the watershed is a manageable unit with respect to both natural processes and as a catchment for contaminants. Reference has already been made to calibrated watershed studies in Canada. Through these, Canada has already made a commitment to watershed level research. The large amount of money involved means there is no turning back.

It was pointed out that the processes of concern in this discussion paper are much broader than the watershed. They are regional to global. Furthermore, watershed limits do not coincide with political boundaries: for example, the Great Lakes Watershed, interpreted as the entire Great Lakes system, includes an international boundary. Ideally, management units should

have physical coherence as well as a "political functional quality." Common sense and pragmatism were recommended:

Budgeting for Research and Rehabilitation

In response to the question, "How should available funds be partitioned between research and rehabilitation of already degraded aquatic systems?" no researcher wanted to see his or her funds taken away, but examples were cited of water treatment that was extremely costly yet accepted by the taxpayers (drinking water treatment and sewage collection and treatment are forms of rehabilitation). The more fundamental question in the context of the present issue "was when do we know enough to take action and who should take it?" The time lag between "learning" and "putting it to use" was noted. A distinction was drawn between the "legacy" of the past in the form of contaminated or otherwise degraded aquatic systems, and the "prevention" approach. Prevention is of course the basis of the quest for control of emissions. The earlier discussion of liming illuminates the difficulties involved in implementing rehabilitation techniques.

The Respective Roles of Federal and Provincial Management of Water Resources

No detailed discussion will be presented for this question, in part because there was little desire to change but rather to "tidy up" the present arrangements. One major point that several interviewees (nearly all from Ontario) addressed, however, was that if we did consider altering the federal-provincial division of responsibility for water, we would need to remember that there are major differences among the provinces in size, in resources, and in problems, such that the smaller and financially weaker "have not" provinces rely more on the federal system than the "have" provinces such as Ontario.

If regulation were entirely a provincial responsibility, and given that there are major differences among provinces, then interprovincial pollution would become an issue comparable, albeit on a smaller scale, to the international transboundary pollutant problem. There were no notable suggestions for solutions to this.

Conclusions and Proposals

1. There is a link between the emission of airborne pollutants and the loading of pollutants in surface waters but the relationship for the major contaminant, sulphur, is not necessarily simple or linear. This limits our ability to predict precisely the consequences to loading of changes in emissions.
   More empirical data should be generated using standardized methods. Development of more sophisticated models and their validation should continue.

2. There are other contaminants as well as acid precursors that enter water bodies through long-range atmospheric transport. These include trace metals and trace organic compounds.

3. The use of modern technology tends to result in the dispersion of airborne pollutants long distances from their sources.

4. The qualitative effects of acidification on the chemistry and biology of aquatic ecosystems are quite well documented. The quantitative relationships between loading and effects are more weakly established. Sensitive systems need to be protected, and a safety margin should be built in.
   Current target loading estimates should be used as a basis to protect the most sensitive systems.

5. Emission controls have been delayed for a number of reasons, both scientific and socioeconomic. Several provinces in Canada now have emission controls for the major sources; to date the United States has not.
   It is crucial that the effects on receiving systems, as well as predictions from models or experiments be documented and made public. This seems to be the closest thing to "proof" that will have political influence.

6. The effects of trace metals and organics upon aquatic biota and people are largely unknown, although potentially extremely harmful.
   Environmental epidemiology as well as environmental toxicology need to be developed as means of assessing damage from trace contaminants. In the interim, risk assessment, based on the (admittedly imperfect) data from environmental toxicology, should be used as a basis for limiting the use of or treating affected water bodies.

7. The long-term fate and effects of contaminants that have accumulated in sediments is not known. The term "time bomb" has been used for these polluted sediments.
   Research on models, empirical measurements and effects of fluxes from sediments, including factors that promote or limit outward fluxes, should continue.

8. A remarkable amount of research has been done on acid precipitation and related phenomena in Europe and North America since the early 1970s. We have some good descriptive data at all levels -- emissions, transport, deposition, and effects -- but process-oriented and mechanistic understanding is still limited.
   Research on mechanisms is not of the highest priority in the context of finding solutions to the problem. But such research should be supported in order to refine our understanding.

9. Good approaches, including monitoring, calibrated watershed studies, experimental manipulation, paleolimnology, toxicology, and modelling, are being applied to the area of concern. There is an abundance of printed material ranging from the popular, the sensational, to the highly technical.

10. Liming acidified or acid-stressed aquatic systems is technically feasible and can improve fisheries. But there are philosophical objections to treating the symptom and not the cause, and major logistical problems that prevent the technique being practicable on a large scale.
    Liming studies on a limited scale and with well-defined goals should be funded and publicized. It is unlikely that with proper management such policy will inhibit action on the source of the problem.

11. Liming requires careful planning and preparatory research.
    Each system may have to be assessed on a site-specific basis when liming is contemplated.

12. Three models were extracted from the discussion on the respective role of scientists in government and universities in terms of research and monitoring: (a) the "blending" model where there is close interaction, joint or cross appointments, and basically no major distinction between the roles, although there will be distinctions between the respective institutional mandates and there might be differences in creativity and accountability; (b) the "spin off" model whereby government science determines the major ongoing long-term research and universities take smaller spin-off "bites," researching them in depth and perhaps with more freedom to be "disinterested"; (c) the "sequential" model in which university researchers produce information that sooner or later, directly or indirectly, is picked up by government and used in decision making and as a basis for policy.

13. There is an acute shortage of funds for environmental research at the federal level.
    The federal government should have some rational process to apportion research funds in relation to policy. A special federal water resource research board and/or an academy at a very senior scientific level should be responsible for review, research direction, and funding at the federal level. Funding proposals for water resource research should normally be judged by peer review and not by nonscientists, with science managers to keep track of direction.

14. The public is concerned for and interested in environmental matters, especially water and toxic substances.
Communication through the media, and by professionally prepared fact sheets should continue and be encouraged.

15. Long-term programs for monitoring the chemical and biological state of air and water are being developed, but not all are standardized or have guaranteed long-term support.
Committed support for routine monitoring and for research to refine and perhaps make some fundamental conceptual changes in monitoring schemes is needed.
Monitoring should be viewed as respectable science, on a par with other types of research.

16. Although acid precursors include oxides of both sulphur and nitrogen, for aquatic systems the major concern to date has been for sulphur, and the resulting proposals for abatement have addressed mainly sulphur for stationary sources.
We may be missing a major issue by de-emphasizing the oxides of nitrogen in stack emissions.
More research should be directed at the significance of the impact of nitrate or nitric acid on aquatic systems.

17. We are in an era of global scale change and environmental degradation in which pollution sources lie at great distances from receptors.
We should promote a broad-scale perspective on ecological degradation, including use of the ecosystem approach and interdisciplinary work at all levels.
Units of water management should not be based on jurisdictional or natural boundaries, but be designed on the basis of common sense.

Appendices

APPENDIX A. PERSONS INTERVIEWED JANUARY-JUNE 1987

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H. Harvey - professor, Department of Zoology,
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A. Hurley - coordinator, Canadian Coalition on Acid Rain, and Perley & Hurley Ltd.,
112 St. Clair Avenue West,
Suite 401,
Toronto, Ontario M4V 2Y3.

M. Keating - environmental reporter,
The Globe and Mail,
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M. Perley - coordinator, Canadian Coalition on Acid Rain, and Perley & Hurley Ltd.,
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H. Regier - professor, Department of Zoology and Institute for Environmental Studies,
University of Toronto,
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D. Whelpdale - professor, Department of Chemical Engineering, and Institute for Environmental Studies,
University of Toronto,
Toronto, Ontario M5S 1A4,
and Senior Research Scientist,
Atmospheric Environmental Service,
Environment Canada,
4905 Dufferin Street,
Downsview, Ontario M3H 5T4.

Informal discussions were also held with:

C. Caccia - Member of Parliament for Davenport, and Liberal environmental critic,
House of Commons, Room 353 S
Ottawa, Ontario M5S 1A4.

L. Barrie - senior research scientist,
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S. Eisenreich - professor, Department of Civil and Mineral Engineering,
University of Minnesota,
Minneapolis, Minnesota,
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R. D. Evans - professor of Environmental Studies, Trent University,
Peterborough, Ontario
K9J 7B8.

J. Ford - research coordinator, Acid Deposition,
Environmental Protection Agency,
200 SW 35th Street,
Corvallis, Oregon 97333.

A. Forester - consultant, Dartside Consulting, 151 Yonge Blvd., Toronto, Ontario M5M 3H3.

R. Hall - scientist, Ontario Ministry of the Environment, Dorset Research Centre, P.O. Box 39, Dorset, Ontario POA 1CO.

D. MacKay - professor, Department of Chemical Engineering and Institute for Environmental Studies, University of Toronto, Toronto, Ontario M5S 1A4.

D. Schindler - senior scientist, Freshwater Research Institute, 501 University Crescent, Winnipeg, Manitoba R3T 2N6.

C. Wren - B.A.R. Environmental Ltd., 532 Queen Street East, Toronto, Ontario M5A 1V2.

APPENDIX B. QUESTIONS USED AS BASIS FOR INTERVIEWS

Our resources for Canadian water management include planning, monitoring, and research.

1. Should government agencies take equal responsibility for in-house work in all three areas, or should research be recognized as more appropriately being carried out in the universities?

2. Critics say that Canada does not spend enough on research. What does this mean? How should research effort be evaluated with respect to national needs? Does Canada (or anyone else) know how to do this/do it?

3. With finite financial resources, how should Canada apportion funds between treatment or rehabilitation measures and research? (If quantitative estimate is not possible, can you give examples or case studies for which we have enough information to justify focusing funds on treatment, versus those for which "more research is needed" before action can be justified.)

4. What would be your personal priorities for research in water-related issues which have direct relevance to policy (compared with curiosity-based or basic research)?

5. The Pearse report recommended the watershed as a unit for water management. Do you consider that this is reasonable from (a) scientific and (b) socioeconomic points of view?

6. Do we need research into monitoring techniques?

The issues related to water quality and quantity have changed over the past few decades. One major change has to do with scale. Climate change and LRTAP as it relates to acidic deposition and "toxic rain" are the major examples of large-scale issues.

7. Are we in Canada addressing these issues adequately? If not, what would be your personal recommendations?

8. Why do you think the federal government has reduced or completely cut off funding for research into toxicology, wildlife toxicology, and environmental toxicology?

The Canadian constitution does not specifically mention water. But we generally interpret the constitution that it gives major responsibility to the provinces for water management.

9. Is the provincial level the most appropriate one for water management?

10. Is a zero-discharge policy supported by research findings? If not, what kind of research needs to be done?

It has been suggested that Canada could be a leader in research for "An environmental industry", i.e., industrial practices which protect the environment. This could form a strong link between environmental and economic objectives.

11. Is this an approach which we are in a position to promote?

12. To what extent can we learn from others or extrapolate research results from elsewhere to the Canadian situation?

13. What about Third World countries? How far do we in Canada have a responsibility towards environment and development in the Third World?

APPENDIX C. TWO NEWS RELEASES GIVING DETAILS OF ONTARIO'S PROGRAM TO REDUCE EMISSIONS OF SULPHUR OXIDES

Ontario

newsrelease / communiqué

Ministry of the Environment | Ministère de l'Environnement

August 13, 1987

FOR FURTHER INFORMATION:

Wayne Scott, 323-5050
APIOS

Cheryl Gullason, 323-4335
Communications Branch

THIRD COUNTDOWN ACID RAIN ABATEMENT REPORTS SUBMITTED

Ontario's four main sulphur dioxide emitters have each submitted a third Countdown Acid Rain progress report, Environment Minister Jim Bradley announced today.

The reports must be filed every six months with the Ministry of the Environment by Inco Ltd. and Falconbridge Ltd. in Sudbury, Algoma Steel Corp. Ltd. in Wawa, and Ontario Hydro. The reports contain details of each emitter's acid rain abatement and research program.

Inco reports it is improving its pyrrhotite rejection process which removes sulphur from the ore before the roasting stage. Research is also continuing on ways to capture more sulphur dioxide from the roasting and smelting stages, while increasing productivity, Inco said.

Falconbridge reports it is continuing to develop ways to increase the rejection of sulphur before smelting the ore. As requested by the Countdown Acid Rain technical review committee, the report provides estimates for the potential reduction of sulphur dioxide emissions for three specific abatement methods. These methods are: increased degrees of roasting in the fluid bed roasters; converter slag cleaning; and, increased pyhrrotite rejection in the Strathcona Mill.

...../2

Ontario Hydro reported that emissions levels were within the legal limits during the first six months of 1987, despite a drought which reduced hydraulic power production. Hydro has held public meetings and prepared the first portion of its Environmental Assessment document, as part of the approval process for its proposed scrubbers.

Algoma Steel has reported that it will continue to meet the Ontario government requirements by operating at a reduced capacity.

A government analysis and summary of the reports is being prepared by the Ministry, and will be published when completed in about a month.

The Countdown Acid Rain program, announced in December 1985, reduces by two-thirds the amount of sulphur dioxide which may be emitted by the four large Ontario sources by 1994.

"The last two progress reports showed us that each polluter was on target in reducing its sulphur dioxide emissions. These latest reports provide more details on how they will achieve the tough new limits of our Countdown program," Mr. Bradley said. "We are showing that acid rain can be stopped when governments act decisively, and that an acid rain abatement program can be both tough and fair.

"Our American neighbors, whose sulphur dioxide emissions cause so much of Ontario's acid rain problem, should take note and then take action to reduce their pollution," he said.

Copies of the company reports are available from Environment Ontario on request.

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Ontario

newsrelease / communiqué

Ministry of the Environment | Ministère de l'Environnement

November 19, 1987

FOR FURTHER INFORMATION:

Wayne Scott, 323-5050
Acid Precipitation Office

GOVERNMENT REVIEW OF THIRD COUNTDOWN ACID RAIN PROGRESS REPORTS RELEASED TODAY

The Ontario government's summary and analysis of the third biannual Countdown Acid Rain Progress Reports was released today by the Ministry of the Environment.

The reports show that Ontario's four major sulphur dioxide emitters are continuing to develop pollution abatement methods to meet Ontario's reduced acid gas emission limits.

INCO

Inco is focusing research and development on both pyrrhotite rejection and bulk smelting. Inco has chosen to maintain the use of its present smelter and develop abatement technology.

In April, Inco used one sixth of the Copper Cliff Mill non-magnetic pyrrhotite circuit to test a pyrrhotite rejection process which had shown encouraging results in pilot plant and laboratory testing. Refinement of this process continues. In late May, Inco conducted a full scale test of its bulk smelting process using a flash furnace over a three week period. Detailed test results will be included in the next progress report.

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The ministry has asked Inco to explore alternate technologies for abatement as part of a contingency plan, and to detail these in future progress reports.

ONTARIO HYDRO

Ontario Hydro has held public meetings near the Nanticoke, Lambton and Lakeview generating stations, as well as at its head office in Toronto, to discuss retro-fitting flue gas desulphurization equipment ("scrubbers") on selected coal-firing generating units. These public meetings are part of the Environmental Assessment process required before scrubbers can be installed. The formal Environmental Assessment document is currently being prepared by Hydro.

The ministry has asked Hydro to specify "a more tangible abatement strategy" in future reports, and to address the use of natural gas, low sulphur coal, purchase of hydraulic power from other provinces, and conservation, as well as the anticipated rate of electricity demand growth.

FALCONBRIDGE

Falconbridge continues to concentrate on improving pyrrhotite rejection, increasing the degrees of roasting in the fluid bed roaster and improving converter slag cleaning. As suggested in the ministry's review of the previous progress report, Falconbridge provided the sulphur dioxide reduction estimates for its abatement strategy.

.../3

ALGOMA STEEL

Algoma Steel confirmed that due to poor market conditions, it would continue to operate its iron ore scintering plant in Wawa at a reduced capacity. Algoma also confirmed that if market conditions improve, it would obtain ore from sources other than Wawa. The ministry stated that acid gas reduction methods would have to be in place before Algoma could significantly increase its production there.

Under Countdown Acid Rain regulations, Inco and Falconbridge in Sudbury, Algoma Steel in Wawa and Ontario Hydro are each required to submit reports every six months, outlining their progress in reducing acid-rain-causing emissions and describing plans for further reductions.

The final reports, due at the end of the three-year technical development period (December 1988 for the three metals companies, and January 1989 for Ontario Hydro) must provide technical and financial details on how each company will achieve the 1994 emission limits. Overall, the required reductions for the four major acid rain polluters are two-thirds from 1980 levels.

The government analysis and summary of the progress reports was prepared by the Ministry of the Environment's Acid Rain technical support committee, with comments from the Ontario Development Corporation and the ministries of Northern Development and Mines, Treasury and Economics, and Energy.

Copies of the government review and the company reports are available on request.

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Mitigation of Surface Water Acidification: To Lime or Not to Lime?

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